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Cherevatsky

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[54] **PRESSURE VESSEL WITH THIN UNSTRESSED METALLIC LINER**

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[51] **Int. Cl.**^{7} **B23P 17/00**

[52] **U.S. Cl.** **220/581**; 220/585; 220/586; 220/590

[58] **Field of Search** 220/581, 585, 220/590, 4.13, 586

[56] **References Cited**

U.S. PATENT DOCUMENTS

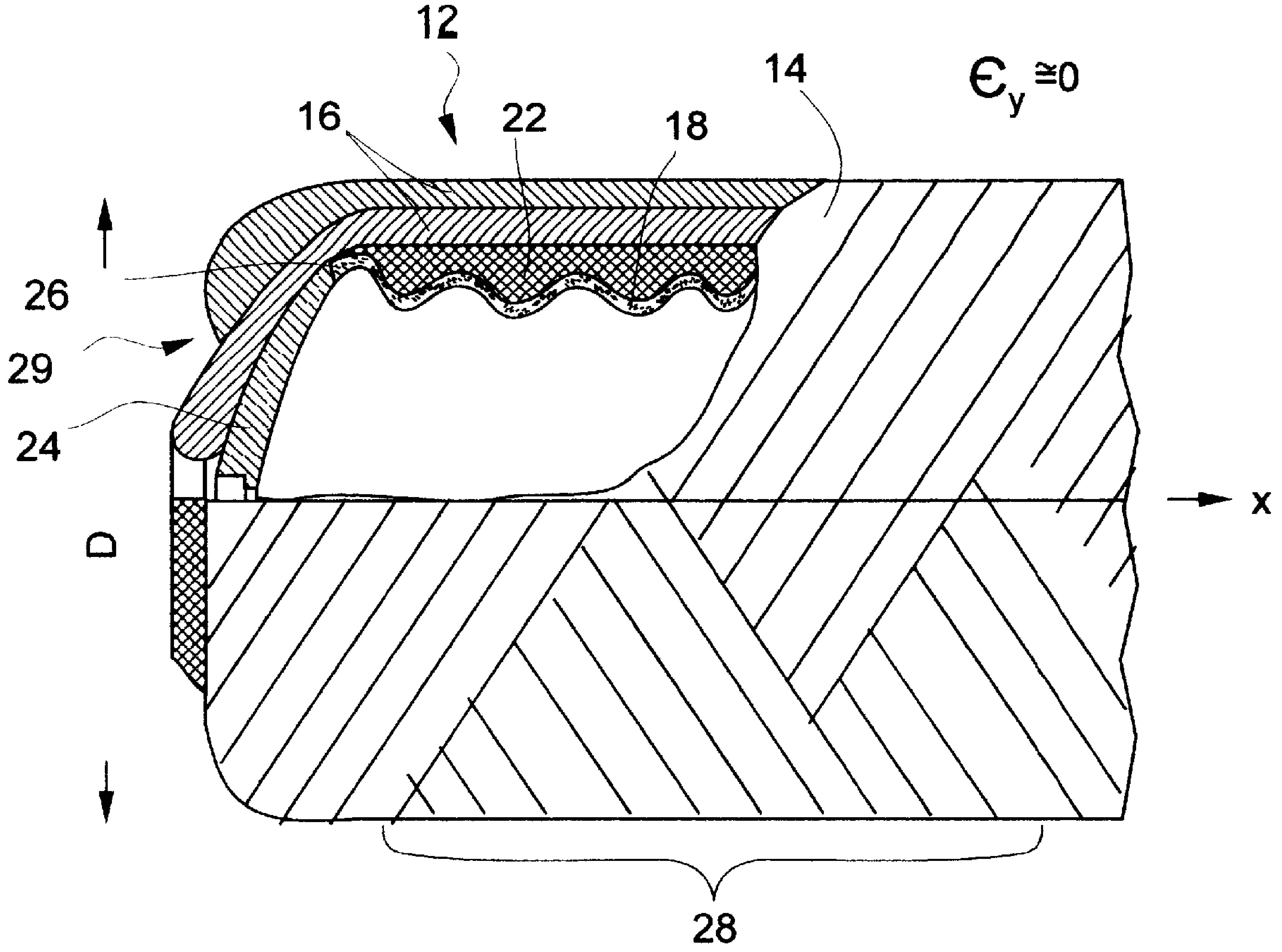
1,968,088	7/1934	Mekler .	
2,988,240	6/1961	Hardesty	220/590
3,066,822	12/1962	Watter	220/581
3,446,385	5/1969	Ponemon	220/590
3,843,010	10/1974	Morse et al.	220/590
3,969,812	7/1976	Beck	220/590 X
4,923,769	5/1990	Jones et al. .	
5,111,971	5/1992	Winer .	
5,292,027	3/1994	Lueke .	
5,590,803	1/1997	Kaempen .	

Primary Examiner—Steven Pollard

[57] **ABSTRACT**

A pressure vessel for containing a fluid at elevated pressure features an unstressed corrugated metallic liner forming part of a hermetic seal. The liner has corrugations extending parallel to a first direction to accommodate deformation in a second direction perpendicular to the first direction. Around the liner is a filler layer of elastic material forming a contiguous layer adjacent to the external surface of the liner and filling the corrugations. An external primary load-bearing container has at least one wall made of fiber-reinforced composite material adjacent to the filler layer. The shape of the primary container, the reinforcing directions of the fiber-reinforced composite material, and the mechanical properties of the filler layer are configured such that, under a given change in the pressure of the contained fluid, a strain caused in the liner parallel to the first direction is at least one order of magnitude less than a corresponding strain in the second direction.

8 Claims, 3 Drawing Sheets



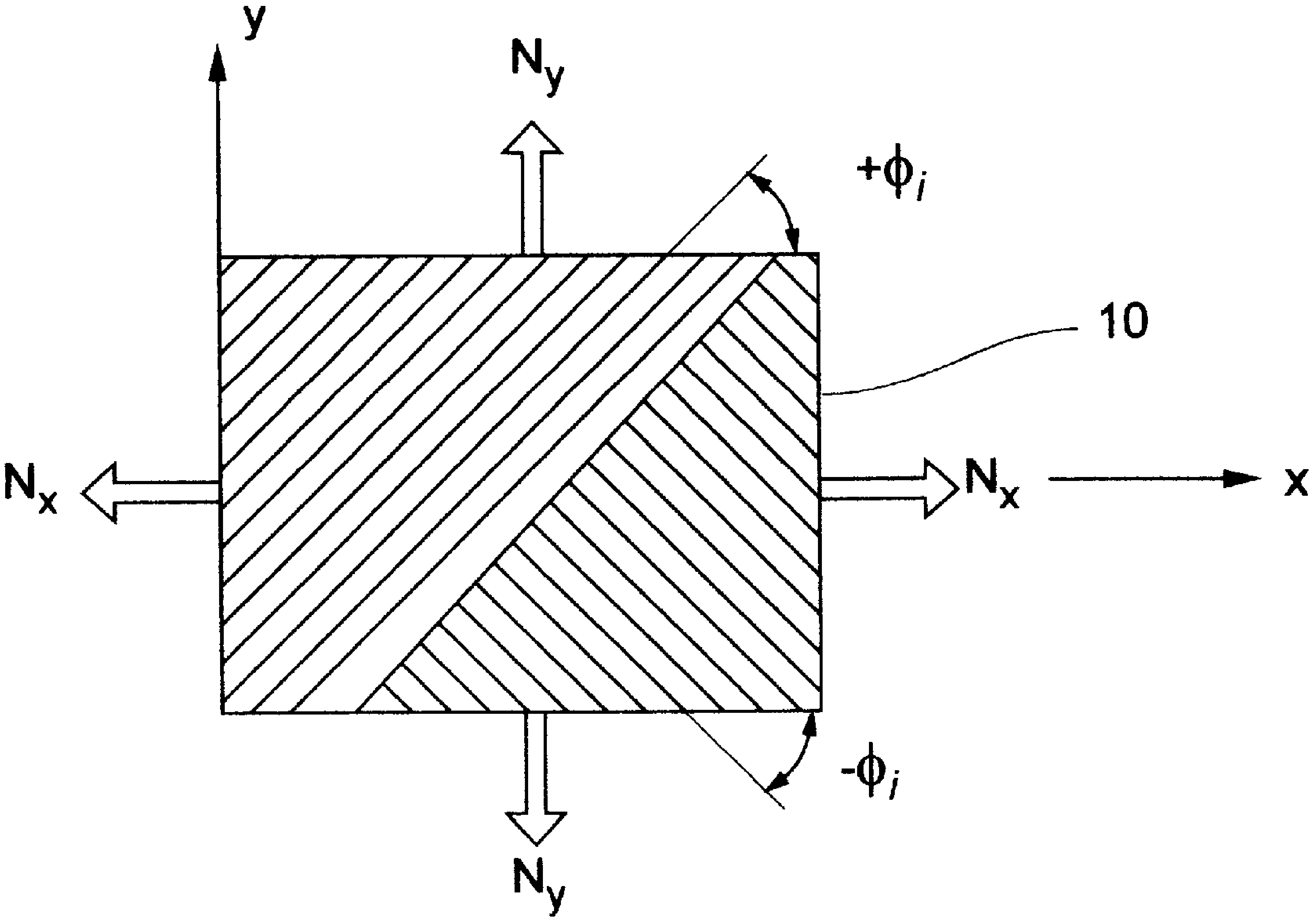
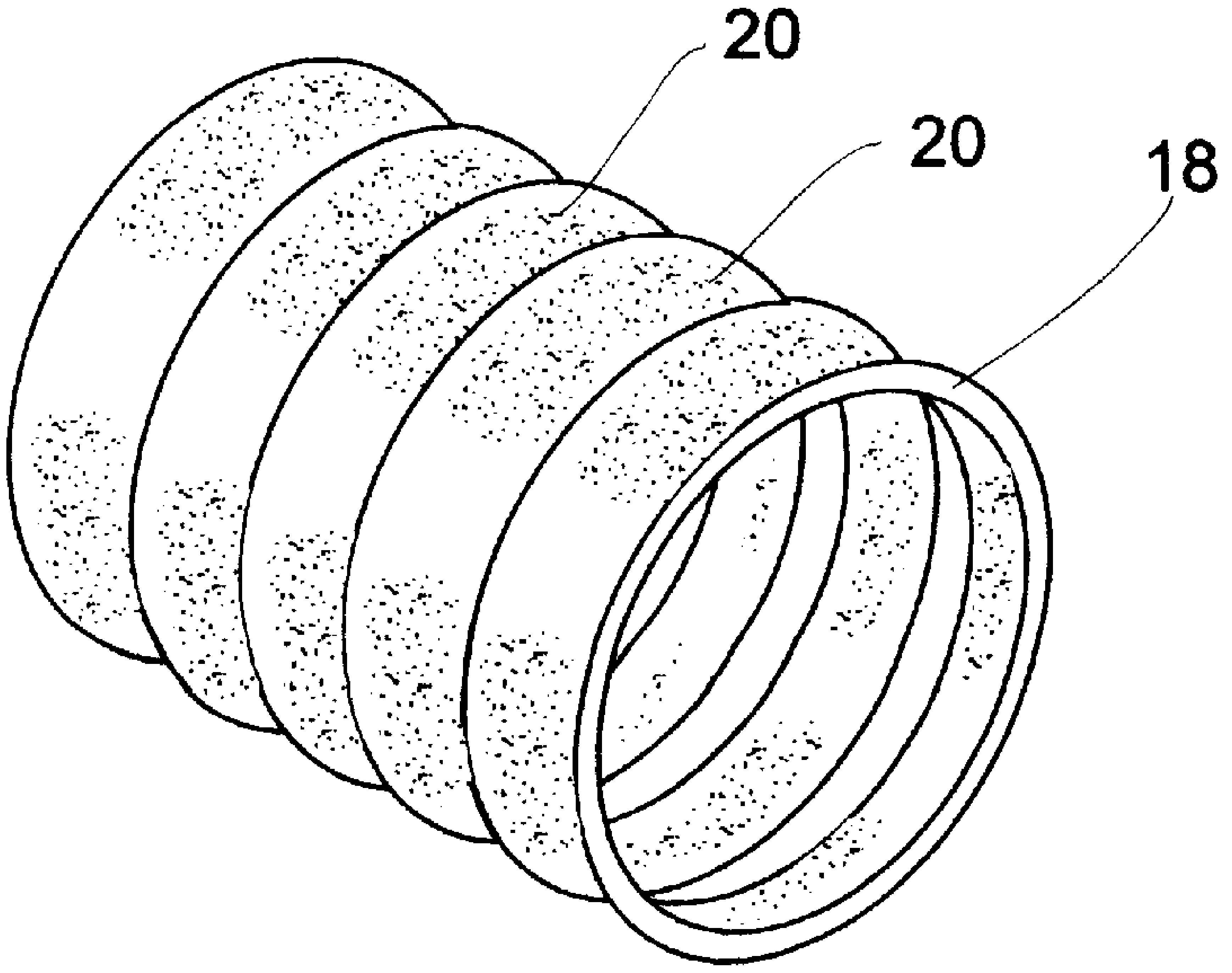


Fig. 1

Fig. 2



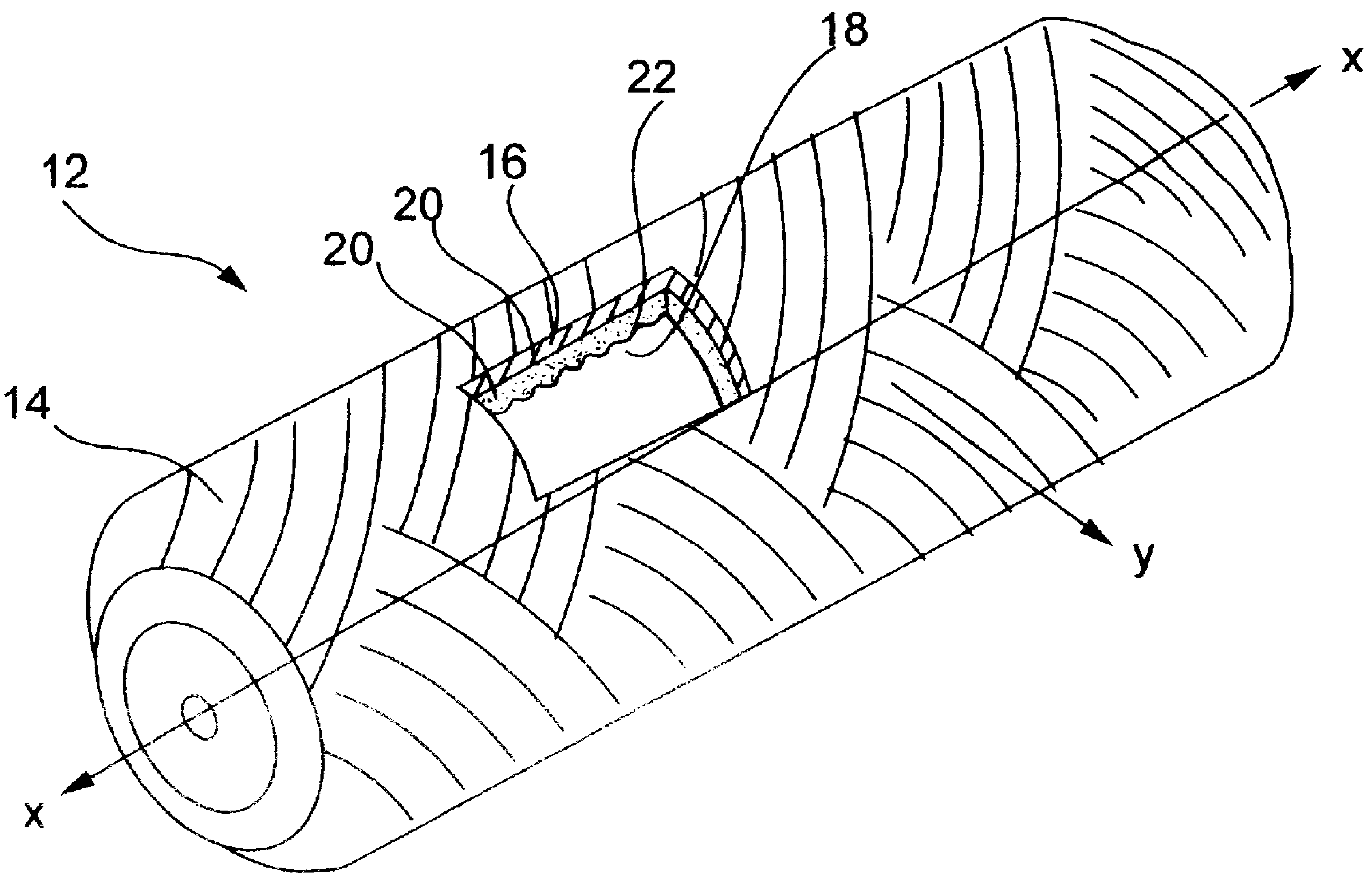


Fig. 3

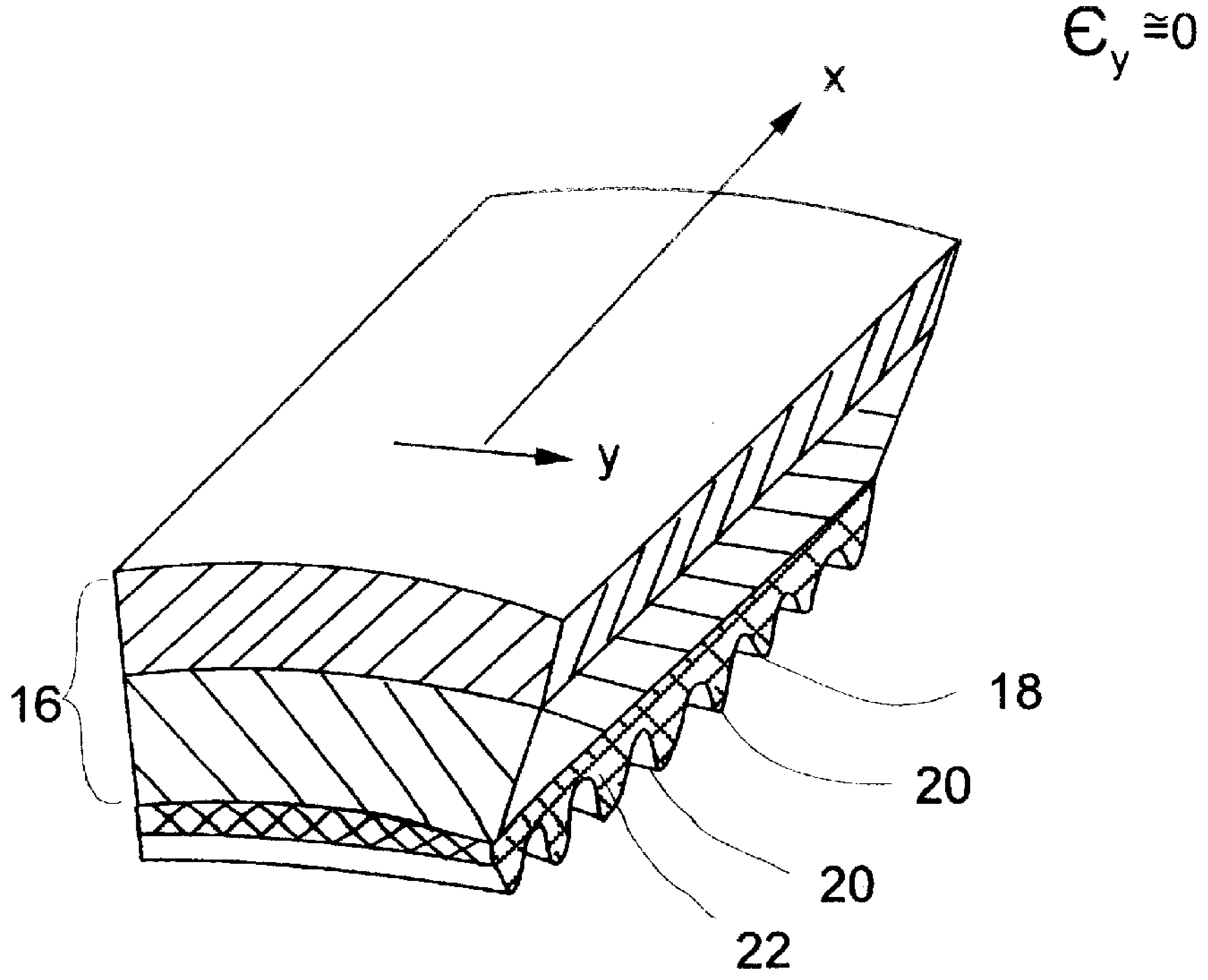


Fig. 4

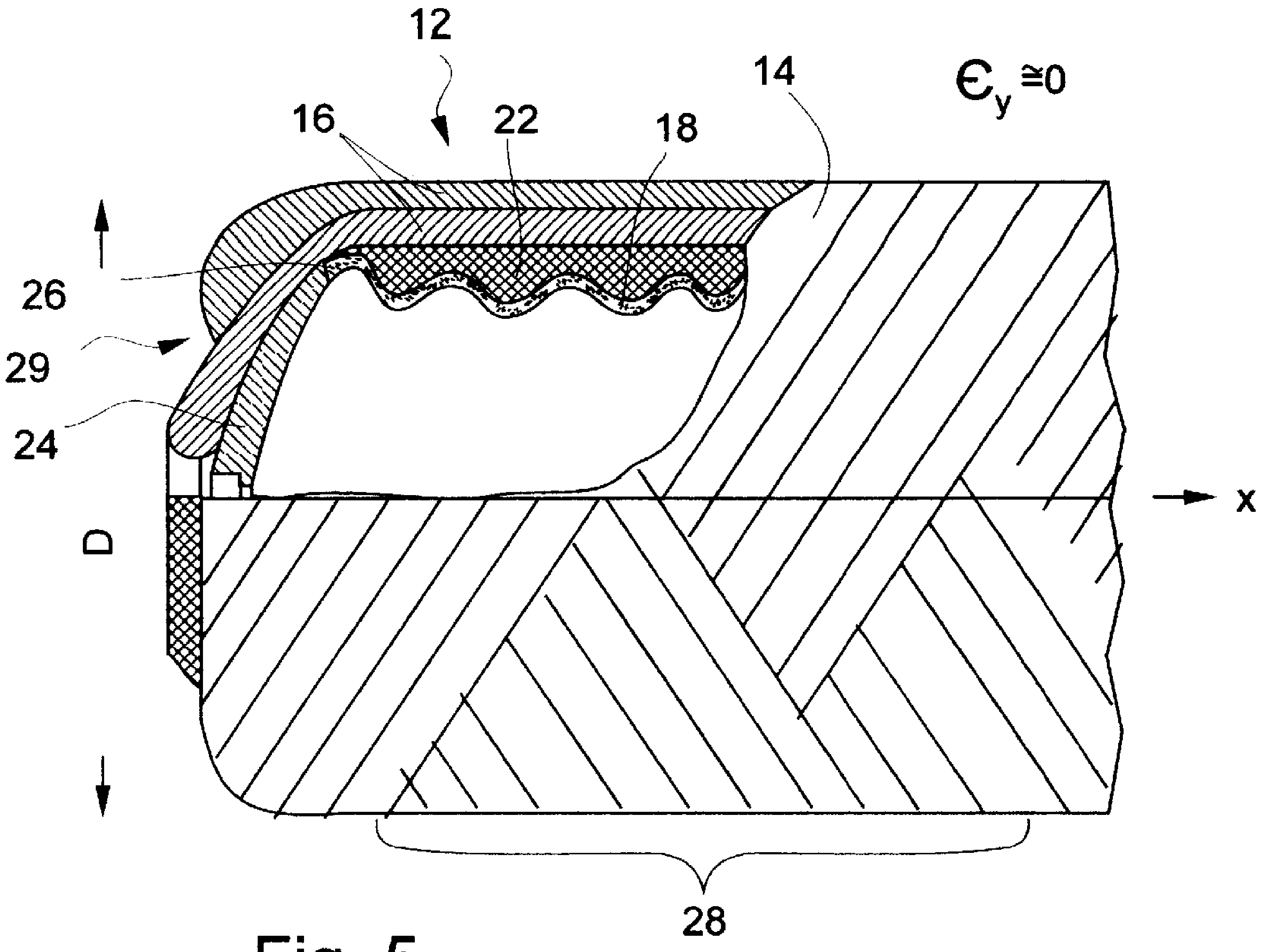

12
16
22
18
14
$\epsilon_y \cong 0$
26
29
24
D
x
28

Fig. 5

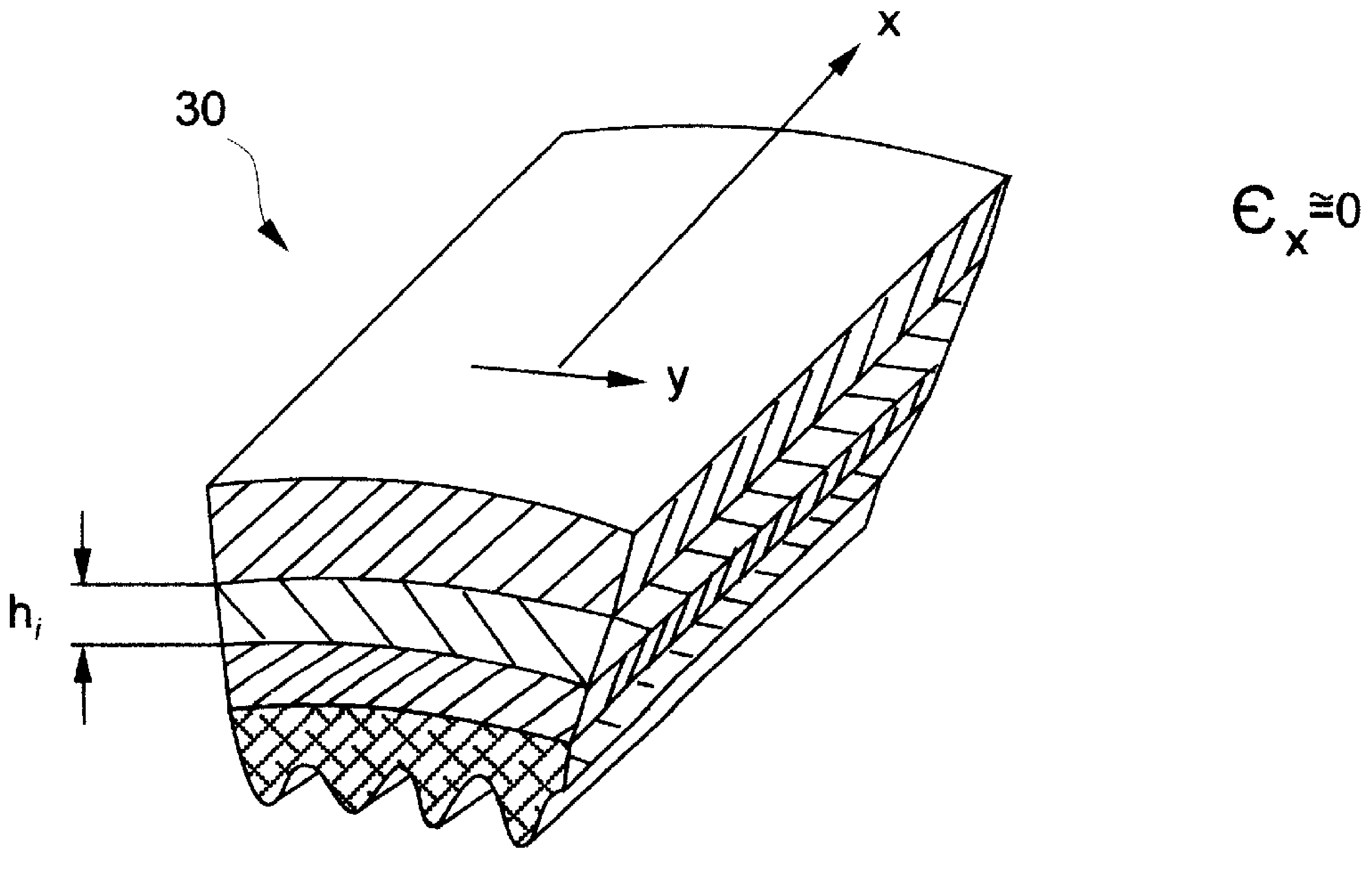

x
30
$\epsilon_x \cong 0$
y
h_i

Fig. 6

PRESSURE VESSEL WITH THIN UNSTRESSED METALLIC LINER

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to pressure vessels and, in particular, it concerns a pressure vessel which has a thin unstressed metallic liner.

A number of different structures are known for containing fluids at elevated pressures. These structures are generally referred to as "pressure vessels". Requirements of safety, as well as attempts to reduce weight, have lead away from the use of simple metallic pressure vessels towards use of reinforced composite materials. In order to provide the required sealing characteristics, however, an additional inner liner must be provided. Hence the two principal types of pressure vessel currently in use both employ reinforced composite containers with either a seamless metallic or thermoplastic liner.

The use of a metallic liner generally provides a much longer operational life, better resistance to harsh environments, and better sealing characteristics than thermoplastic liners. The design of pressure vessels with metallic liners, however, presents its own particular problems, as will now be described.

Composite pressure vessels with metallic liners are manufactured by filament winding of fibers impregnated with resin matrix, together forming the composite material, around the metallic liner. The metal liner of these structures bears part of the applied internal pressure. In addition, incompatibility of the ranges of elastic behavior of the metal liner and composite material lead to residual compression stresses in the liner as a result of the "proof pressure" test ("autofrittage phenomenon").

During subsequent application of internal pressure, the liner stretches and experiences corresponding tensile stress. In order to withstand these tension/compression stresses through repeated filling cycles over an extended period of usage, the liner must be relatively thick. Besides the clear implications of a thick liner for the weight of the vessel, the presence of a thick metallic layer also leads to safety problems.

In an effort to address these problems, attempts have been made to develop an unstressed metallic liner in which a thin metallic layer provides sealing properties while transferring all of the pressure load to the surrounding primary vessel. An example of such a structure is described in U.S. Pat. No. 5,292,207 to Lueke.

In order to avoid stressing of the liner, Lueke suggests a complicated "herringbone" pattern of parallelogram-like elements which provides undulations in two orthogonal directions. As a result, the liner readily stretches in any direction to conform to the deformation of the primary vessel.

The structure suggested by Lueke presents numerous problems of practical implementation. Firstly, the liner appears to contact the primary vessel at isolated points. Pressure applied to such a structure would not be effectively transferred to the primary vessel walls, and would probably result in immediate destruction of the herringbone pattern. Furthermore, the complicated structure would be extremely difficult to manufacture.

Another reference, U.S. Pat. No. 1,968,088 to Mekler, although less relevant than the Lueke reference, will be mentioned for its superficial similarity to one embodiment of the present invention. Mekler, in a patent filed before the introduction of reinforced composite materials into the art, describes a freely-expanding, corrugated protective liner for reaction vessels subjected to rapidly varying temperatures. The corrugations serve to prevent distortion and damage to the liner under extreme heat stress, while insulating the main vessel from the most extreme of the temperature variations. The reference does not address issues of performance under elevated pressure.

The structure described by Mekler is not suitable for use with fluids at elevated pressures. Since no solution is suggested for accommodating heat stress along the direction of elongation of the corrugations, it would appear that the liner must have a clearance from the ends of the primary vessel. As a result, the liner must be designed to bear a large proportion of any internal pressure. Additionally, no support is provided for the corrugations of the liner. Thus, if the liner was made from thin materials, the corrugated structure would rapidly deform and collapse under internal pressure. Finally, since this reference pre-dates the use of reinforced composite materials, Mekler clearly fails to teach any synergy between a liner structure and specific configurations of such composite materials.

There is therefore a need for pressure vessels with thin unstressed metallic liners which are convenient to produce and which effectively transfer applied pressure to the walls of the primary container.

SUMMARY OF THE INVENTION

The present invention is a pressure vessel which has a thin unstressed metallic liner.

According to the teachings of the present invention there is provided, a pressure vessel for containing a fluid at elevated pressure, the pressure vessel comprising: (a) a primary load-bearing container formed with at least one wall made of fiber-reinforced composite material, the shape of the primary container and the reinforcing directions of the fiber-reinforced composite material being configured such that, under a given change in the pressure of the contained fluid, a strain of the wall in a first direction is at least one order of magnitude less than a corresponding strain in a second direction perpendicular to the first direction; (b) an unstressed corrugated metallic liner positioned adjacent to at least part of an inner surface of the wall and forming part of a hermetic seal within the primary container, the liner having corrugations extending substantially parallel to the first direction such that the liner conforms to deformation of the wall in the second direction; and (c) a filler layer of elastic material interposed between the liner and the wall so as to substantially fill raised portions of the corrugations.

According to a further feature of the present invention, the filler forms a substantially contiguous layer between the liner and the inner surface of the wall.

According to a further feature of the present invention, the filler is substantially incompressible.

According to a further feature of the present invention, wherein the filler has a module of elasticity of less than about 10^4 kg.cm^{-2}.

According to a further feature of the present invention, the primary container has a cylindrical portion and dome-shaped end portions, the liner being deployed along substantially all of the inner surface of the cylindrical portion.

According to a further feature of the present invention, the corrugations form circumferential rings within the cylindrical portion.

According to a further feature of the present invention, the corrugations extend parallel to a central axis of the cylindrical portion.

According to a further feature of the present invention, the hermetic seal is completed by at least one additional metallic element, the additional metallic element being sealingly connected to the liner by welding.

According to a further feature of the present invention, the liner is made from metallic material having a given coefficient of thermal expansion, and wherein the internal structure of the fiber-reinforced composite material is configured so as to generate an effective coefficient of thermal expansion of the wall as measured along the first direction substantially equal to the given coefficient.

There is also provided according to the teaching of the present invention, a pressure vessel for containing a fluid at elevated pressure, the pressure vessel comprising: (a) an unstressed corrugated metallic liner forming part of a hermetic seal, the liner having corrugations extending substantially parallel to a first direction such that the liner accommodates deformation in a second direction perpendicular to the first direction, the liner having an external surface; (b) a filler layer of elastic material disposed as a substantially contiguous layer adjacent to the external surface of the liner and substantially filling the corrugations; and (c) a primary load-bearing container surrounding the hermetic seal, the primary container being formed with at least one wall made of fiber-reinforced composite material adjacent to the filler layer, wherein the shape of the primary container, the reinforcing directions of the fiber-reinforced composite material, and the mechanical properties of the filler layer are configured such that, under a given change in the pressure of the contained fluid, a strain caused in the liner parallel to the first direction is at least one order of magnitude less than a corresponding strain in the second direction.

There is also provided according to the teachings of the present invention, a method for producing a pressure vessel for containing a fluid at a given working pressure which is to be tested at a corresponding proof-test pressure, the method comprising: (a) providing a liner made from metallic material and configured so as to accommodate deformation in a first in-plane direction; and (b) constructing around the liner a primary container having a multiple layer wall made from fiber reinforced composite material, the thickness of the layers, the reinforcing directions of fibers within each layer, and the mechanical and physical properties of the fibers in each layer being chosen such that, when the liner is filled with fluid at the proof test pressure, deformation of the liner along a second in-plane direction perpendicular to the first in-plane direction is limited to within the elastic limit of the metallic material.

According to a further feature of the present invention, a layer of elastic filler material is provided between the liner and the primary container, the filler material being substantially incompressible, wherein the thickness of the layers, the reinforcing directions of fibers within each layer, and the mechanical and physical properties of the fibers in each layer of the primary container are chosen such that application of increased pressure within the liner generates a strain in the wall as measured in the second in-plane direction at least one order of magnitude less than the corresponding strain as measured in the first in-plane direction.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. **1** is a schematic plan view illustrating the definitions of the in-plane loads acting on a section of a pressure vessel wall;

FIG. **2** is a schematic isometric representation of a first corrugated liner for use in a pressure vessel according to a first embodiment of the present invention;

FIG. **3** is a partially cut-away isometric view of a pressure vessel according to the first embodiment of the present invention;

FIG. **4** is an enlarged view of the cut-away section of FIG. **3**;

FIG. **5** is a partially cut-away side view of the pressure vessel of FIG. **3**;

FIG. **6** is a view equivalent to FIG. **4** for a pressure vessel according to the second embodiment of the present invention;

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a pressure vessel which has a thin unstressed metallic liner.

The principles and operation of pressure vessels according to the present invention may be better understood with reference to the drawings and the accompanying description.

Referring now to the drawings, FIG. **1** introduces certain nomenclature which will be useful in understanding the details of the present invention. Specifically, there is shown a section of wall, generally designated **10**, of a pressure vessel. Outward pressure exerted by the fluid is resisted by tensile forces within the wall. For each arbitrary small section **10** of the wall, these forces are shown resolved into two orthogonal in-plane components, designated here N_x and N_y. According to the convention used below in the context of a cylindrical structure, N_x is taken to be parallel to the central axis of the cylinder and N_y is in a circumferential direction.

Turning now to FIGS. **2**–**5**, a first embodiment of a pressure vessel, generally designated **12**, will now be described. Generally speaking, pressure vessel **12** includes a primary load-bearing container **14** formed with at least one wall **16** made of fiber-reinforced composite material. Adjacent to at least part of an inner surface of wall **16** is an unstressed corrugated metallic liner **18** which forms part of a hermetic sealing shell within primary container **14**. Liner **18** has corrugations **20** extending in a first direction, in this case the circumferential "y" direction, which allow liner **18** to conform to any deformation of wall **16** perpendicular to the length of corrugations **20**, i.e., in this case parallel to the axial "x" direction. A filler layer **22** of elastic material is interposed between liner **18** and wall **16** so as to substantially fill raised portions of corrugations **20**. In order to avoid stressing of the liner in the "y" direction, the shape of primary container **14**, the internal structure of the fiber-reinforced composite material, and the mechanical properties of filler layer **22** are configured to greatly reduce, and preferably substantially eliminate, stress applied to liner **18** in that direction as will be described below.

By way of example, the present invention will be illustrated with reference to two specific embodiments having a generally cylindrical vessel shape. This simplifies the calculations required, as will be detailed below. However, it would be appreciated that the invention is not limited to cylindrical shapes, and can be readily adapted to a wide range of other types of vessel.

The present invention is particularly advantageous in that it allows use of a very thin liner to provide the required sealing. Typically, the thickness of the liner is less than about one hundredth of the internal diameter of the vessel, and preferably, between about 5×10^{-3} and about 5×10^{-4} of the internal diameter. Since relatively small quantities of metal are required, it becomes feasible to make the liner from expensive unreactive metals and alloys which do not react with corrosive fluid contents. Examples of materials from which liner **18** may be produced include, but are not limited to, steel, aluminum, copper, nickel and tungsten.

It should be noted that the present invention may be used to advantage with vessels for containing fluids at a wide range of elevated pressures. For smaller vessels of diameter up to about 0.5 m, the vessels of the present invention are typically used for working pressures in excess of about 100 atm., and frequently up to as much as about 300 atm. However, the present invention is not limited to use within these ranges. In particular with larger vessels, the features of the present invention may be used to advantage with vessels for working pressures of tens of atm.

Parenthetically, the term "in-plane", used herein to refer to the direction of loads and strains within the vessel walls, is taken to refer to directions lying within a plane tangential to the general extensional directions of the wall at a given point. Thus, in a cylindrical form, the in-plane directions are along the line of a circumferential ring (to be referred to as the "y" direction) and parallel to the axis of the cylinder (to be referred to as the "x" direction).

Turning now to the features of pressure vessel 12 in more detail, FIG. 2 shows liner **18**, configured to form part of an inner sealing shell of pressure vessel **12** according to the present invention. Liner **14** has a generally cylindrical form featuring a large number of corrugations **20** (shown not to scale) in the form of circumferential rings.

The exact profile of corrugations **20** is typically not critical to the present invention. Preferably, the corrugations are smooth, i.e., without any sharp corners or angles, so as to avoid local concentration of deformation stresses. Typically, a roughly sinusoidal shape is used, although other rounded shapes such as alternating arcuate portions may equally be used.

FIGS. **3–5** illustrate the overall structure of pressure vessel **12** incorporating liner **18**. As best seen in FIG. **5**, the hermetically sealing shell of the pressure vessel is typically completed by metallic, dome-shaped end pieces **24** attached to the ends of liner **18**. In contrast to prior art pressure vessels, the unstressed nature of liner **18** allows end pieces **24** to be connected at a welded joint **26**.

Immediately adjacent to the outer surface of liner **18** is filler layer **22**, substantially filling corrugations **20**. Clearly, the word "filling" as used here in relation to corrugations **20** refers to filling of what appear from the outside to be "depression lines" corresponding to the recessed parts of the corrugation pattern. Alternatively, as considered relative to the internal volume of the liner, filler layer **22** may be considered to fill the "raised" inwardly-projecting parts of the corrugation pattern. Preferably, in addition to filling the corrugations, filler **22** also provides a substantially continuous layer so as to form a mechanically insulating sleeve between liner **18** and wall **16**.

It is a particular feature of filler **22** that it has low resistance to change of shape so as to allow flexing of the corrugations to accommodate deformation. This condition is satisfied by using an "elastic" material, defined herein as a material having a modulus of elasticity of less than about 10^4 kg.cm^{-2}. Preferably, filler **22** is made from a material having a modulus of elasticity of less than about 10^3, and typically less than about 100 kg.cm^{-2}.

Preferably, in addition to the aforementioned elasticity, filler **22** exhibits a high resistance to compression under uniform pressure. Specifically, as will be explained below, filler **22** is preferably substantially incompressible, i.e., substantially retains its total volume, under the working conditions of the pressure vessel to the extent that liner **18** is suppressed by wall **16** without significant additional deformation due to compression of the filler. Examples of materials exhibiting the desired combination of elasticity and incompressibility include, but are not limited to, natural and synthetic rubber.

Around filler layer **22** are wound multiple layers of composite material, preferably in an axisymmetric configuration, to form load-bearing wall **16**. The resulting wall **16** typically includes a generally cylindrical wall portion **28** along the length of liner **18** and dome-shaped end portions **29** which retain end pieces **24**. The materials used for producing the composite material layers may be selected from any of the range of fiber materials and resin matrices conventionally used in the art.

Turning now briefly to FIG. **6**, this shows a section, generally designated **30**, from a second embodiment of a pressure vessel constructed and operative according to the teachings of the present invention. Section **30** is similar to the section illustrated in FIG. **4**, except the corrugations **20** here extend parallel to the "x" direction. The requirements of the overall vessel structure correspondingly become that the strain transferred to the liner is near-zero in the "x" direction. In all other respects, the structure and operation of the second embodiment will be fully understood by analogy to the first embodiment described above.

As mentioned above, it is a particular feature of the pressure vessels of the present invention that the shape of primary container **14**, the reinforcing directions of the fiber-reinforced composite material, and the mechanical properties of filler layer **22** are configured such that, under a given change in the pressure of the contained fluid, a strain caused in liner **18** parallel to the length of corrugations **20** is at least one order of magnitude less than a corresponding strain in a direction perpendicular to the length of the corrugations. As implied by this statement, both the shape of the vessel and the properties of the filler layer may vary, thereby affecting the required characteristics of the composite material. For example, if a compressible filler is used, the fiber structure can be designed to exhibit negative deformation in the direction parallel to the corrugations so that the liner exhibits near-zero net stress in that direction. However, for ease of analysis, the theoretical treatment of design of a pressure vessel according to the present invention will be limited to a preferred case in which the vessel is substantially cylindrical and the filler is substantially incompressible. In this case, the required condition for the composite material may be expressed simply as near-zero strain in a wall **16** in a direction perpendicular to the length of the corrugations.

Before addressing the theoretical treatment, reference is made to a text entitled "Mechanics of Composite Materials" (Robert M. Jones, 1975, Scripta Book Company, Washington, D.C.) which is hereby incorporated by reference. This text, and in particular sections 2.6 and 4.5.4 thereof, present the theoretical treatment which serves as the basis for the following analysis.

The following treatment characterizes the properties of the i^{th} layer of the composite material in terms of its elastic moduli E_1^i, E_2^i, G_{12}^i, its Poisson coefficient μ_{12}^i, its winding angle ϕ_i (see FIG. **1**), and its thickness h_i. The average elastic characteristics for a symmetrically reinforced structure (i.e., for each winding layer with angle $+\phi_i$ there is a corresponding layer with angle $-\phi_i$) are:

$$B_{11}=\sum_{i=1}^{k}h_i(E_1^{-i}\cos^4\varphi_i+2E_1^{-i}\mu_{12}^i\sin^2\varphi_i\cos^2\varphi_i+E_2^{-i}\sin^4\varphi_i+G_{12}^i\sin^2 2\varphi_i)$$

$$B_{12}=$$

$$\sum_{i=1}^{k}h_i[(E_1^{-i}+E_2^{-i})\sin^2\varphi_i\cos^2\varphi_i+E_1^{-i}\mu_{12}^i(\sin^4\varphi_i+\cos^4\varphi_i)-G_{12}^i\sin^2 2\varphi_i]$$

$$B_{22}=\sum_{i=1}^{k}h_i(E_1^{-i}\sin^4\varphi_i+2E_1^{-i}\mu_{12}\sin^2\varphi_i\cos^2\varphi_i+E_2^{-i}\cos^4\varphi_i+G_{12}^i\sin^2 2\varphi_i)$$

$$E_{1,2}^{-i}=\frac{E_{1,2}^i}{1-\mu_{12}^i\mu_{21}^i};\qquad E_1^i\mu_{12}^i=E_2^i\mu_{21}^i$$

Under axisymmetric loading, the in-plane forces N_x,N_y are:

$$N_x=B_{11}\epsilon_x+B_{12}\epsilon_y$$

$$N_y=B_{12}\epsilon_x+B_{12}\epsilon_y$$

where ϵ_x, ϵ_y are the in-plane strains. It follows that:

$$\varepsilon_x=\frac{B_{22}N_x-B_{12}N_y}{B_{11}B_{22}-B_{12}^2};$$

$$\varepsilon_y=\frac{B_{11}N_y-B_{12}N_x}{B_{11}B_{22}-B_{12}^2}$$

For a cylindrical shell under internal pressure:

$$N_y=2N_x$$

If follows from the above that

$$\epsilon_x=0 \text{ if } B_{22}=2B_{12}$$

$$\epsilon_y=0 \text{ if } 2B_{11}=B_{12}$$

Using net-theory approximations, the following simplified relations may be obtained:

$$\varepsilon_x=0 \quad\text{if}\quad \sum_{i=1}^{k}E_1^ih_i\sin^2\varphi_i(3\cos^2\varphi_i-1)=0$$

$$\varepsilon_y=0 \quad\text{if}\quad \sum_{i=1}^{k}E_1^ih_i\cos^2\varphi_i(3\cos^2\varphi_i-1)=0$$

By varying the winding angles, layer thickness and the elastic properties of the fiber materials used, it is possible simultaneously to satisfy the above conditions together with optimal distributions of stresses in the layers.

For example, for $\epsilon_x=0$ corresponding to an implementation of the invention with corrugations extending longitudinally, calculations were performed for layers of glass and carbon fibers which have a ratio of elastic moduli of 1:3. The following parameters were found to satisfy the required conditions:

glass reinforcing layer: $\mathring{A}_1=90.00°$,

carbon reinforcing layer: $\mathring{A}_2=35.26°$, with $h_1=h_2$.

It is an additional preferred feature of certain implementations of the present invention that the internal structure of the fiber-reinforced composite material is configured so as to generate an effective coefficient of thermal expansion (CTE) of wall **16** as measured along the direction parallel to corrugations **20** which is substantially equal to that of liner **18**. This condition can be achieved by selecting the layer thickness and reinforcement angles to satisfy an additional set of equations set out below. In the direction perpendicular to the corrugations, the corrugations flex to conform to the thermal expansion of wall **16**.

The coefficients of thermal expansion for a symmetrically reinforced structure are:

$$\alpha_x=\frac{B_{1t}\cdot B_{22}-B_{2t}\cdot B_{12}}{B_{11}B_{22}-B_{12}^2}$$

$$\alpha_y=\frac{B_{2t}\cdot B_{11}-B_{1t}\cdot B_{12}}{B_{11}\cdot B_{22}-B_{12}^2}$$

where

$$B_{1t}=\sum_{i=1}^{k}h_i[E_1^{-i}(\alpha_1^i+\mu_{12}^i\alpha_2^i)\cos^2\varphi_i+E_2^{-i}(\alpha_2^i+\mu_{21}^i\alpha_1^i)\sin^2\varphi_i]$$

$$B_{2t}=\sum_{i=1}^{k}h_i[E_1^{-i}(\alpha_1^i+\mu_{12}^i\alpha_2^i)\sin^2\varphi_i+E_2^{-i}(\alpha_2^i+\mu_{21}^i\alpha_1^i)\cos^2\varphi_i]$$

and a_1^i and a_2^i are coefficients of thermal expansion for unidirectional material in fiber direction and perpendicular direction, respectively.

It will be appreciated that the above descriptions are intended only to serve as examples, and that many other embodiments are possible within the spirit and the scope of the present invention.

What is claimed is:

1. A pressure vessel for containing a fluid at elevated pressure, the pressure vessel comprising:

(a) a primary load-bearing container formed with at least one wall made of fiber-reinforced composite material, the shape of said primary container and the reinforcing directions of said fiber-reinforced composite material being configured such that, under variations in the pressure of the contained fluid within a given range, a strain of said wall in a first direction is at least on order of magnitude less than a corresponding strain in a second direction perpendicular to said first direction;

(b) an unstressed corrugated metallic liner positioned adjacent to at least part of an inner surface of said wall and forming part of a hermetic seal within said primary container, said liner having corrugations extending substantially parallel to said first direction such that said liner conforms to deformation of said wall in said second direction; and

(c) a filler layer of elastic material interposed between said liner and said wall so as to substantially fill raised portions of said corrugations, wherein said liner is made from metallic material having a given coefficient of thermal expansion, and wherein the internal structure of said fiber-reinforced composite material is further configured so as to generate an effective coefficient of thermal expansion of said wall as measured along said first direction substantially equal to said given coefficient.

2. The pressure vessel of claim **1**, wherein said filler forms a substantially contiguous layer between said liner and said inner surface of said wall.

3. The pressure vessel of claim **1**, wherein said filler is substantially incompressible.

4. The pressure vessel of claim **1**, wherein said filler has a module of elasticity of less than about 10^4 kg.cm^{-2}.

5. The pressure vessel of claim **1**, wherein said primary container has a cylindrical portion and dome-shaped end portions, said liner being deployed along substantially all of the inner surface of said cylindrical portion.

6. The pressure vessel of claim **5**, wherein said corrugations form circumferential rings within said cylindrical portion.

7. The pressure vessel of claim **5**, wherein said corrugations extend parallel to a central axis of said cylindrical portion.

8. The pressure vessel of claim **1**, wherein said hermetic seal is completed by at least one additional metallic element, said additional metallic element being sealingly connected to said liner by welding.

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